Reply to Comment on ‘Formation of bound states of electrons in spherically symmetric oscillations of plasma’

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Abstract

I reply here to the comment of Dr Shmatov on my recent work and demonstrate the invalidity of his criticism of the classical physics description of the formation of bound states of electrons participating in spherically symmetric oscillations of plasma.
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Nowadays there is a lack of a universally recognized theoretical model of stable natural plasma structures existing in the atmosphere [1]. An approach to the description of such a plasmoid based on radial oscillations of electron gas was recently put forward in Refs. [2–4]. Oscillations of electrons were treated in both quantum and classical frameworks [2] within the proposed model. Various important phenomena, such as emission of high energy radiation, which arise in spherically symmetric plasma oscillations, were also predicted [3]. Note that other theoretical descriptions of natural plasmoids, including very exotic ones, were reviewed in Ref. [5].

In Ref. [4] I analyzed the possibility of the formation of bound states of electrons participating in spherically symmetric oscillations due to the exchange of ion acoustic waves. Note that in Ref. [4] the dynamics of electron oscillations was treated in frames of the classical electrodynamics. In the comment on my work made by Dr. Shmatov [6], it was claimed that the classical physics description adopted in Ref. [4] is inconsistent with the numerical estimates presented in my paper, since the typical energy of an electron participating in oscillations is below the minimal kinetic en-

ergy E_{q} (see Ref. [6]) resulting from the Heseinberg uncertainty principle.

I disagree with the statement of Ref. [6] that classical electrodynamics is invalid for the description of the bound state formation. Indeed, to form a bound state the energy of the effective attraction should be greater than the kinetic energy of electrons (see, e.g., Ref. [7]). As in Ref. [4] we can discuss singly ionized nitrogen plasma with the background electron density $n_0 = 10^{15}\,\mathrm{cm}^{-3}$ and electron temperature $T = 10^5\,\mathrm{K}$, which corresponds to the typical plasma of a gas discharge [8]. Note that this value of T is different from that used in Ref. [4]. Taking the amplitude of electron oscillations $a \sim 10^2 k_{\mathrm{e}}^{-1}$, where k_{e} is the Debye wave number, and the distance between oscillating electrons $d \sim 10a$ as well as using Eq. (16) from Ref. [4], we get that the effective attraction takes place if $|\omega_{\mathrm{i}} - \Omega| \leq 10^{-4}\omega_{\mathrm{i}}$, where ω_{i} is the ion Langmuir frequency and Ω is the frequency of the electron motion. Note that in this case the kinetic energy of electrons prevails both the energy of their thermal motion $\sim$ several eV and $E_{\mathrm{q}} \sim 10^{-18}\mathrm{eV}$.

Thus I have demonstrated that the classical electrodynamics description of the bound state formation of electrons participating in radial oscillations is still valid although one should choose the values of the parameters of the system, like T, d, and a, different from those in Ref. [4]. Nevertheless, I thank Dr. Shmatov for pointing out in his comment [6] the unsuccessful choice of the parameters in my work [4].

Finally I mention that electron harmonic motion on the frequency $\Omega < \omega_{\mathrm{i}}$ should not be necessarily treated as forced oscillations as in Ref. [4]. It was demonstrated in Ref. [9] that a plasma oscillation has to be considered as a wave packet where both rapid and slow motions are present since a monochromatic Langmuir wave is likely to be unstable [10]. Thus the results of Ref. [4] can be applied to those electrons which participate in slow oscillations.

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